

Insolation & Earth's Energy Budget

10/16 Preclass: Make meaning of the graphs!

Agenda

- Presentations (10 mins)
- Debriefing the lab
 - Insolation & differential heating
- Lecture on weather & climate
 - Earth's energy budget
 - Transport of heat from tropics → poles

The Earth's Revolution around the Sun

at **equinox**, the circle of illumination passes through both poles

the subsolar point is the equator

each location on Earth experiences 12 hours of sunlight and 12 hours of darkness

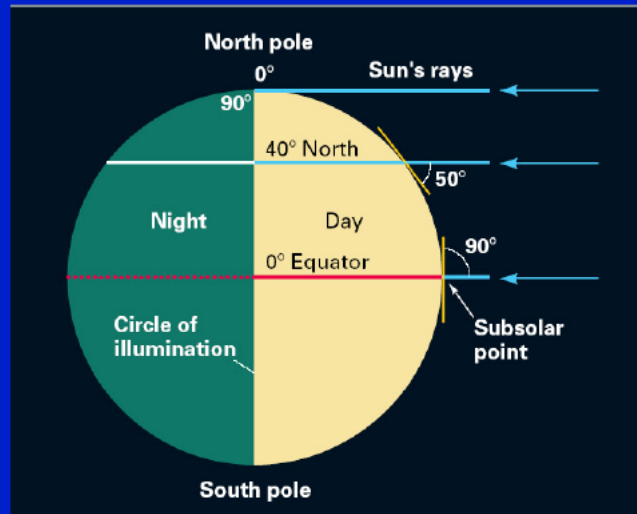
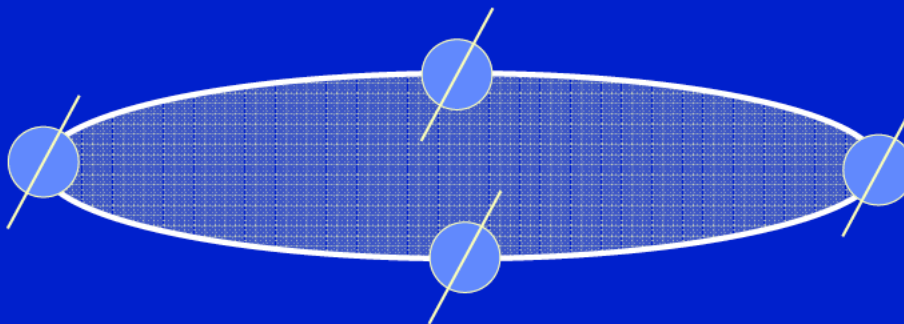


Figure 1.18, p. 41

The Earth's Revolution around the Sun

the Earth rotates about its axis from west to east once every 24 hours

the Earth's axis points same way (parallelism) as it revolves around the sun



The Earth's Revolution around the Sun

the four seasons occur because the Earth maintains a constant orientation (tilted $23\frac{1}{2}^\circ$ with respect to the perpendicular to the plane of the ecliptic) as it revolves around the sun

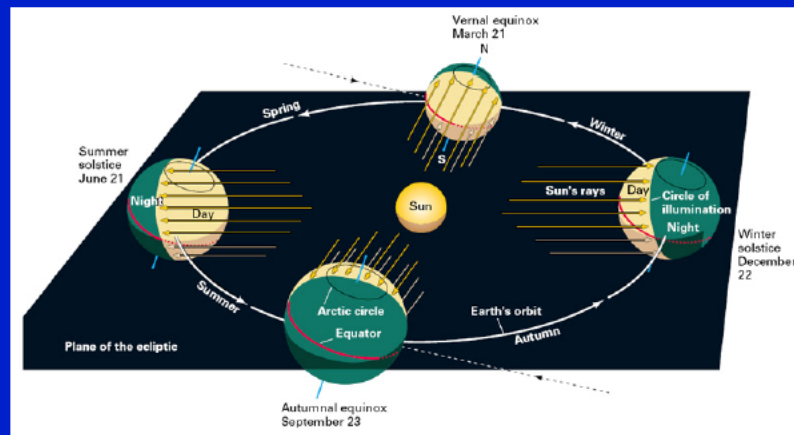


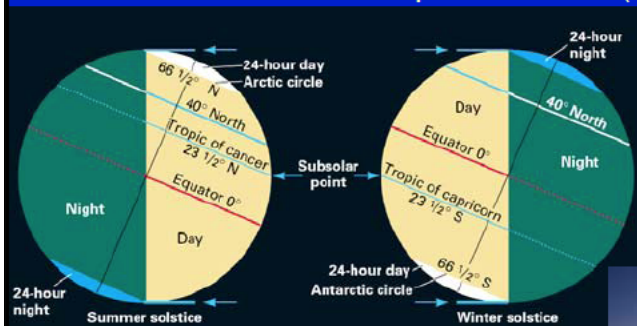
Figure 1.17, p. 40

The Earth's Revolution around the Sun

Solstice ("sun stands still")

On June 22, the subsolar point is $23\frac{1}{2}^\circ$ N (Tropic of Cancer)

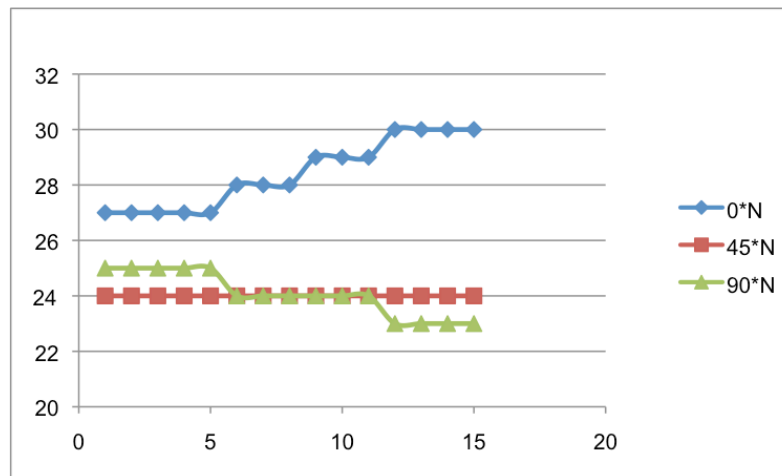
On Dec. 22, the subsolar point is $23\frac{1}{2}^\circ$ S (Tropic of Capricorn)



How and where might this photo have been taken? →

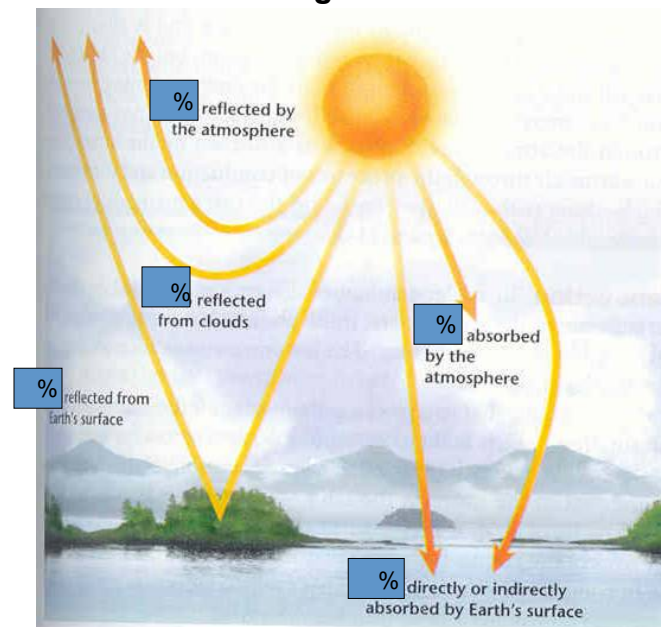


Lab "data" Temperature vs. Time



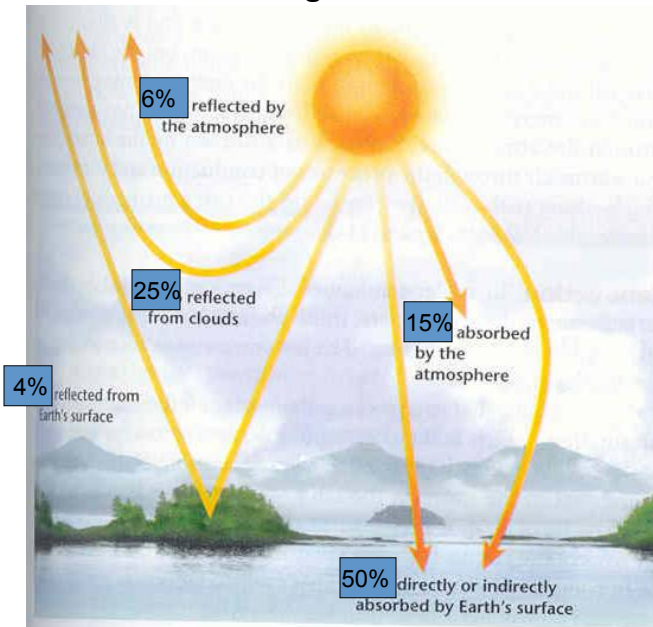
Solar Radiation Budget

Fill in the correct percentages in the diagram to the right.



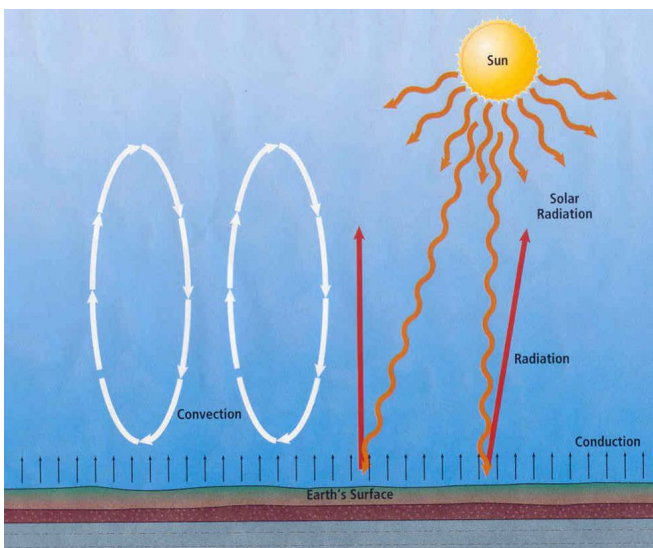
Solar Radiation Budget

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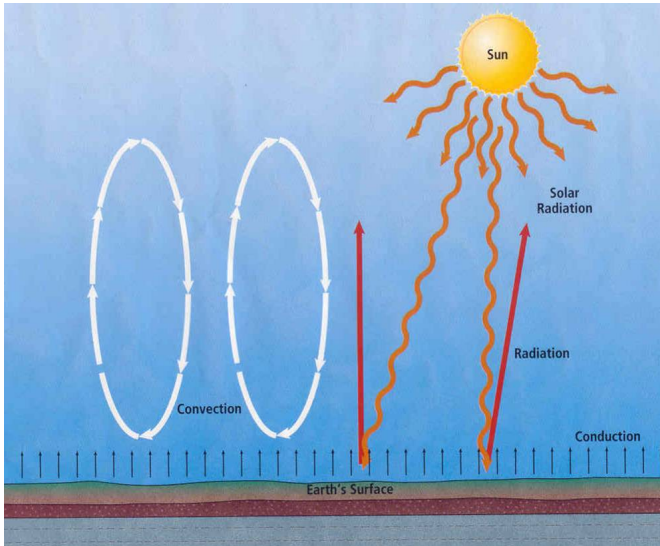
Heat Transfer Processes

1. _____ - Sun heats Earth's surface in the form of rays or waves
2. _____ - Earth's warm surface heats lower atmosphere by direct contact
3. _____ - heat is distributed by warm air rising and cold air sinking



Heat Transfer Processes

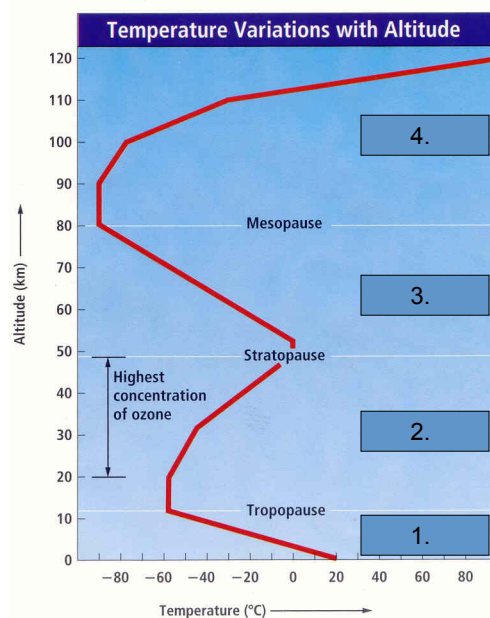
1. Radiation - Sun heats Earth's surface in the form of rays or waves
2. Conduction - Earth's warm surface heats lower atmosphere by direct contact
3. Convection - heat is distributed by warm air rising and cold air sinking



Atmospheric Structure

Label the layers of the atmosphere below:

1. _____ - contains dust, moisture, weather.
2. _____ - contains protective ozone
3. _____ - coldest layer
4. _____ - contains auroras, high temperature



Atmospheric Structure

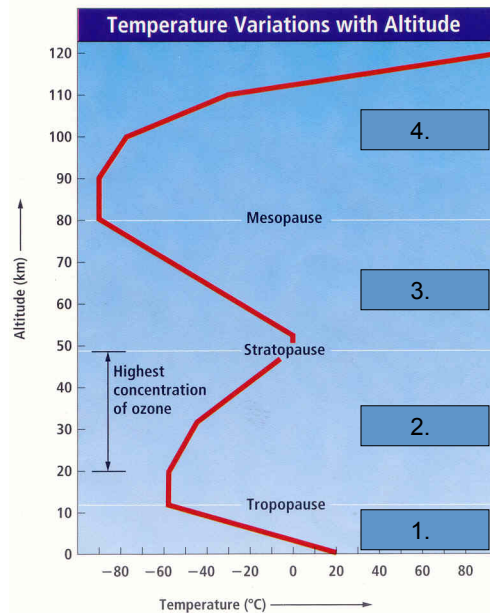
Label the layers of the atmosphere below:

1. Troposphere - contains dust, moisture, weather.

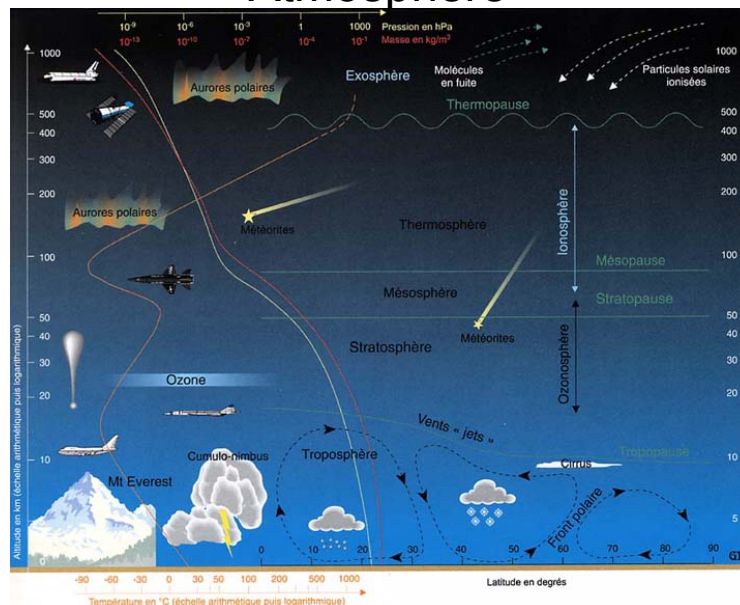
2. Stratosphere - contains protective ozone

3. Mesosphere - coldest layer

Thermosphere
4. _____ - contains auroras, high temperature

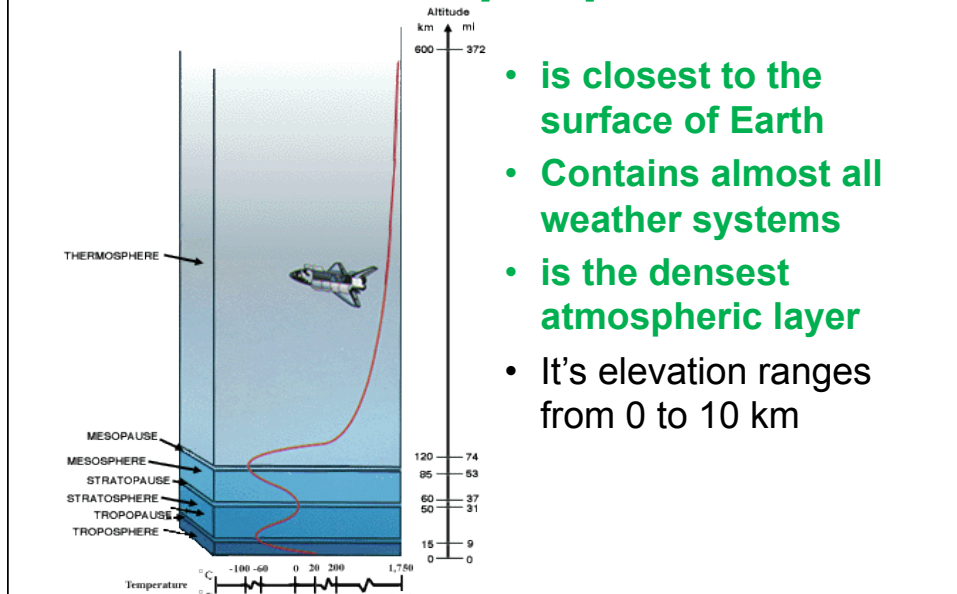


Atmosphere



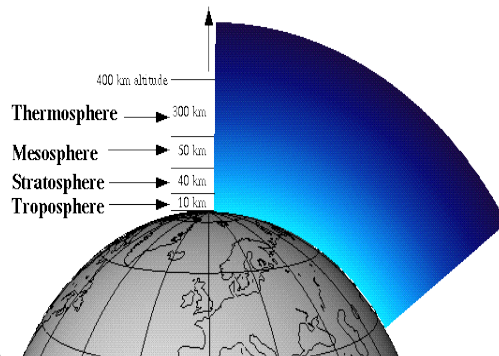
The surrounding air of the Earth

1. The troposphere:



2. The Stratosphere:

- sits on top of the troposphere
- contains the ozone (O_3) layer, which protects us from most UV radiation
- Define Tropopause:
- Average elevation: 10 km to around 50 km



Atmospheric Density

- **Density and pressure in the atmosphere decrease exponentially with height**
- **Approximately 75% of the total mass of the atmosphere is in the troposphere**
- **Approximately 99% of the mass of the atmosphere is the troposphere and stratosphere**

Weather and Climate

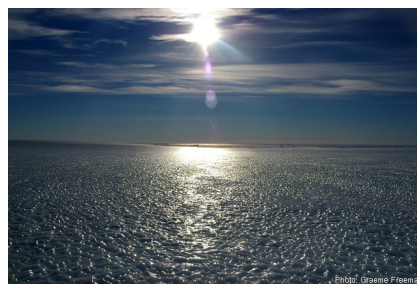
Weather

- The **weather** is a set of all the phenomena occurring in a given atmosphere at a given time.



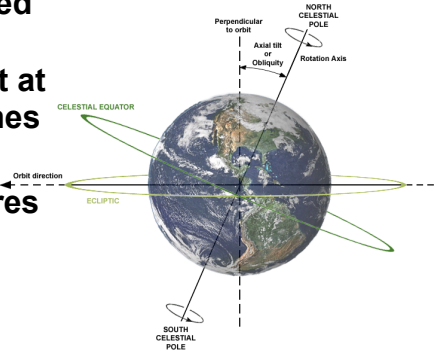
What causes weather?

- Weather occurs due to density differences between one place to another.
 - = a function of air temperature & moisture
 - = function of differences in the sun angle at any particular spot, which varies seasonally by latitude from the tropics.



Surface Temperature Differences

- Because the Earth's axis is tilted relative to its orbital plane ("ecliptic"), sunlight is incident at different angles at different times of the year.
- On Earth's surface, temperatures usually range $\pm 40^{\circ}\text{C}$ (-40°F to 104°F) annually.
- Uneven solar heating
 - formation of zones of temperature and moisture gradients
 - "frontogenesis"



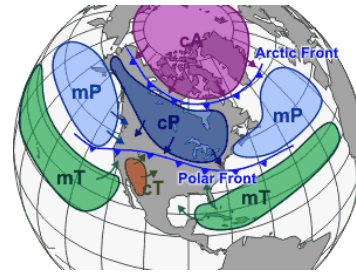
Weather Phenomena

- On Earth, common weather phenomena include wind, cloud, rain, snow, fog and dust storms.
- Less common events include natural disasters such as tornadoes, hurricanes and ice storms.
- Almost all familiar weather phenomena occur in the troposphere (the lower part of the atmosphere).



Weather Fronts

- A **weather front** is a boundary separating two masses of air of different densities
 - the principal cause of meteorological phenomena: *density gradient* → *turbulence*!
- In surface weather analyses, fronts are depicted using various colored lines and symbols, depending on the type of front.
- The air masses separated by a front usually differ in temperature and humidity.



Air Mass Characteristics

Variables

- Area of Formation
- Altitude (high or low)
- Temperature (warm or cold)
- Moisture Content
- Movement Patterns
- Size
- Speed

Effects

Types of Fronts and their Weather

- **Cold fronts** may feature narrow bands of thunderstorms and severe weather, and may on occasion be preceded by squall lines or dry lines.
- **Warm fronts** are usually preceded by precipitation and fog.
- **Occluded fronts** are formed during the process of cyclogenesis when a cold front overtakes a warm front. A wide variety of weather can be found along an occluded front, with thunderstorms possible, but usually their passage is associated with a drying of the air mass.



A dramatic black and white shot of an arcus cloud associated with a severe squall line April 11 2007

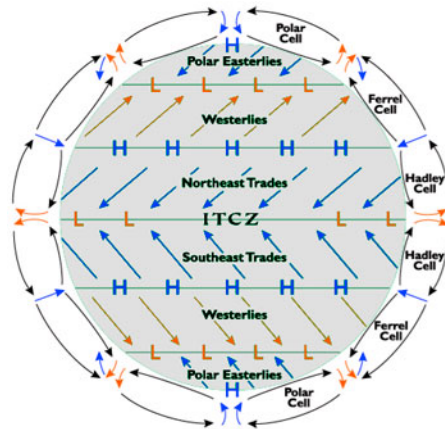
Wind

- Surface temperature differences in turn cause pressure differences.
- A hot surface heats the air above it and the air expands, lowering the air pressure and its density. The resulting horizontal **pressure gradient** accelerates the air from high to low pressure, creating wind.



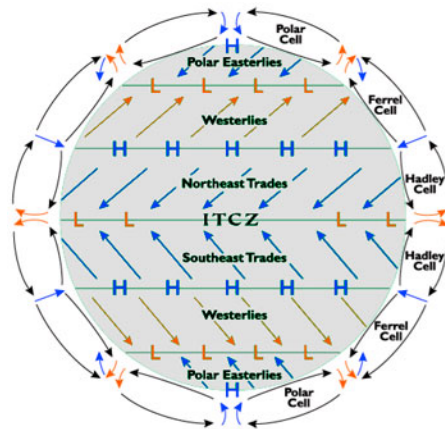
Major Circulation Systems of the Earth

- On or near the equator, where average solar radiation is greatest, air is warmed at the surface and rises. This creates a band of **low air pressure, centered on the equator.**



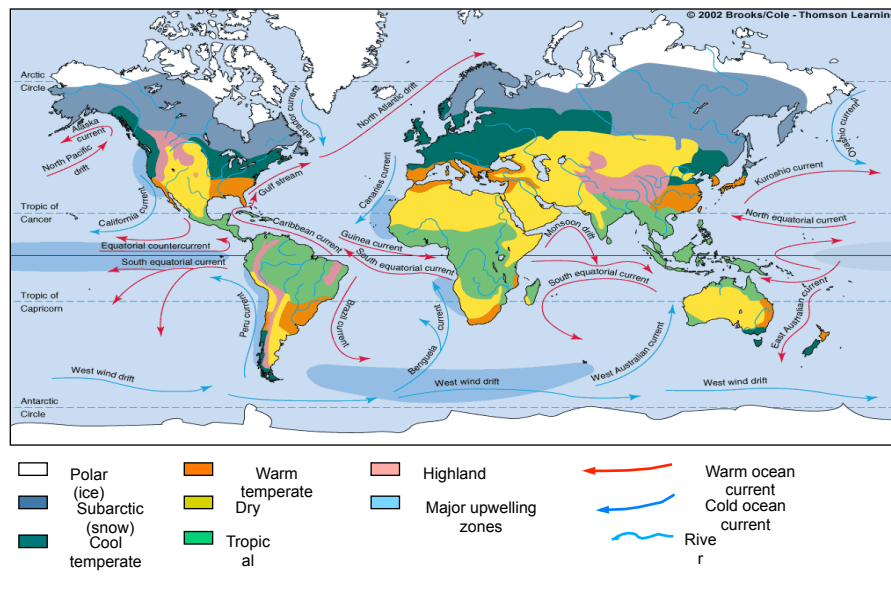
Major Circulation Systems of the Earth MAIN POINT!

- Wind & ocean currents transport heat & moisture from TROPICS → POLES!**
- There are three gear-like “cells”
 - Hadley cells (0 – 30° N, S)
 - Ferrell cells (30 – 60° N, S)
 - Polar cells (60 – 90° N, S)
- Label the moisture & temp!**



CONNECTIONS TO ECOLOGY

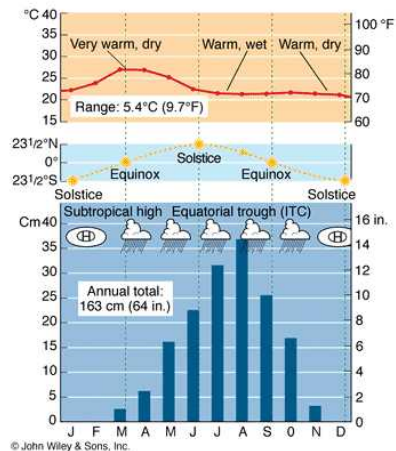
Biome Classifications depend on Climate



Climographs

Mean (average) monthly

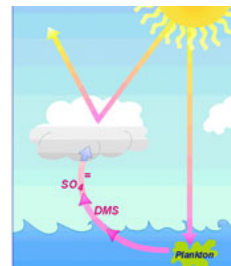
- Temperature
- Rainfall
- Insolation



Wet-dry tropical / Tropical Savanna (Aw) climate:
 Timbo, Guinea, at lat. 10°N, West Africa. A wet season at time of high sun alternates with an almost rainless dry season at time of low sun. The location is alternately influenced by the Subtropical High (November-May) and the Intertropical Convergence (ITC) low. Distinct temperature cycle -- hottest before rainy season. Temperature range = 9.7°F (5.4°C). Precipitation total = 64 in (163 cm). "Savanna" vegetation associations occur here -- "big game" country of Africa. Savanna = grassy plain with scattered trees.

Marine Organisms and Cloud Formation

- Scientists are learning that **marine organisms** can also affect the types of clouds that form.
- Many plankton release a chemical called **dimethyl sulfide** into the atmosphere. This chemical undergoes a series of reactions in the air to form sulfate particles.
- **Vapor condenses around these particles to form clouds.** These clouds have smaller droplets than other clouds.
- They therefore are **brighter and reflect more sunlight back out into space**, preventing the sunlight from reaching and heating Earth's surface.



Phytoplankton in the ocean produce dimethyl sulfide (DMS) that is converted to sulfate aerosols (SO₄), which influence the amount of sunlight reflected by clouds.

Who cares???

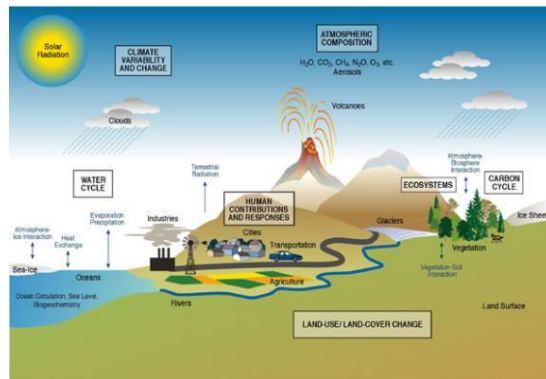
Kenya's Farmers Struggle with Weather Changes

<http://www.npr.org/templates/story/story.php?storyId=6510673>

The screenshot shows a Mozilla Firefox browser window displaying the NPR website. The address bar shows the URL <http://www.npr.org/templates/story/story.php?storyId=6510673>. The page title is "Kenya's Farmers Struggle with Weather Changes" by Gwen Thompson. The article text begins with "All Things Considered, November 19, 2006 - Weather patterns in Kenya are far different than they were a generation ago. There's less snow on the mountaintops, lakes are much lower, and the rainy season has been arriving late. And when the rain finally comes, it falls too hard and fast and sweeps away the precious topsoil that farmers need to plant their harvests." The page also features a sidebar with "LOCAL STATIONS", "BROWSE TOPICS", and "SERVICES". The bottom of the page shows the Windows taskbar with the Start button and several open applications.

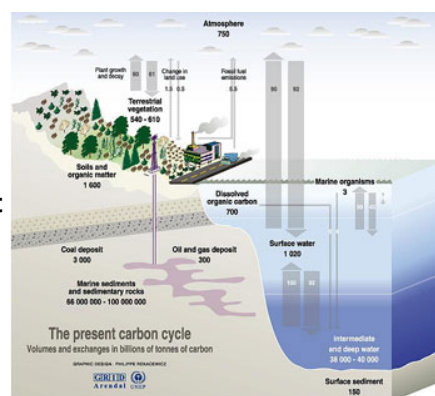
Climate Change

- Describes changes in the variability or average state of the atmosphere over time scales ranging from decades to millions of years.
- These changes can be caused by internal processes, (e.g. plate tectonics), or external forces (e.g. variations in sunlight intensity) or, more recently, human activities.



Oceans and Climate Change

- Photosynthetic marine organisms remove carbon dioxide from the environment to build carbohydrates.
- Ocean water holds tremendous quantities of carbon dioxide, 40 times more than the atmosphere. It absorbs almost half of the carbon dioxide released from the burning of fossil fuels.
- Ocean water also absorbs tremendous quantities of heat. As the atmosphere warms due to the buildup of greenhouse gases, it transfers some of this heat to the ocean, slowing the pace of climate change.



Weather Shapes the Planet

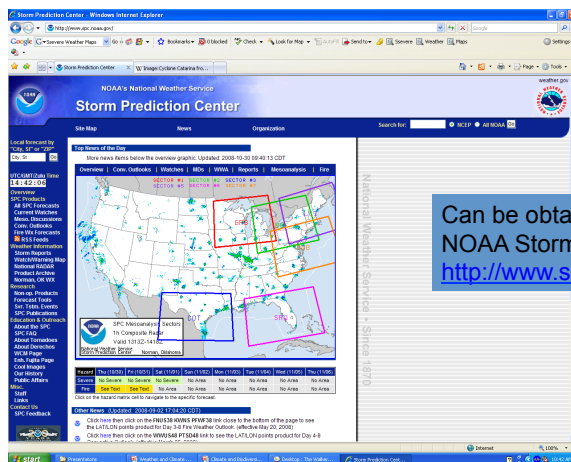
Weather Shapes the Earth

- Weather is one of the fundamental processes that shape the Earth. The process of weathering breaks down rocks and soils into smaller fragments and then into their constituent substances.



Storm surge from Hurricane Katrina.

Severe Weather Maps



Can be obtained from
NOAA Storm Prediction Center
<http://www.spc.noaa.gov/>

Immediate Effects of Severe Weather

- Heavy Rain or Snow
- Lightening
- Thunder
- Flooding
- Storm Surges
- Heat Waves



Aftereffects of Severe Weather

- Destruction of Property
- Contamination of Drinking Water
- Power Outages
- Loss of Life
- Increase of Insurance Policies



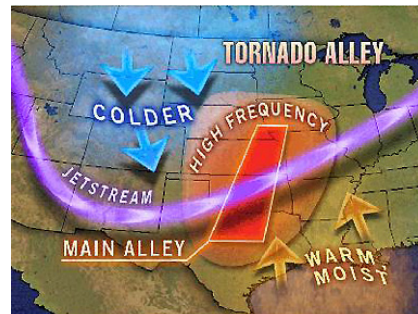
Tornados

- A violent, rotating column of air in contact with both the surface of the earth and a cumulonimbus cloud.
- Most tornadoes have wind speeds between 40 mph (64 km/h) and 110 mph (177 km/h), are approximately 250 feet (75 m) across.
- Tornadoes normally rotate counterclockwise in the northern hemisphere, clockwise in the southern.
- Although tornadoes have been observed on every continent except Antarctica, most occur in the United States.
- In the United States, on average tornadoes are around 500 feet (150 m) across, and stay on the ground for 5 miles (8 km).



Tornado Alley

- Includes: Arkansas, Kansas, Missouri, Oklahoma and Texas.
- North-South mountain ranges surround the central plains and may be an underlying cause of extreme weather patterns in the central plains.



Fujita Scale

Fujita tornado damage scale		
Scale	Wind estimate	Typical damage
F0	40-72 mph	Light damage. Some damage to chimneys, branches broken off trees, shallow-rooted trees pushed over, sign boards damaged.
F1	73-112 mph	Moderate damage. Peels surface off roofs, mobile homes pushed off foundations or overturned, moving autos blown off road.
F2	113-157 mph	Considerable damage. Roofs torn off frame houses, mobile homes demolished, boxcars overturned, large trees snapped or uprooted, cars lifted.
F3	158-206 mph	Severe damage. Roofs and some walls torn off well-constructed houses, trains overturned, most trees in forests uprooted, heavy cars lifted.
F4	207-260 mph	Devastating damage. Well-constructed houses leveled, structures with weak foundations blown away for some distance, cars thrown.
F5	261-318 mph	Incredible damage. Strong frame houses leveled off foundations and swept away, trees debarked, automobile-size objects fly in excess of 100 meters.

Source: National Weather Service

Staff graphic

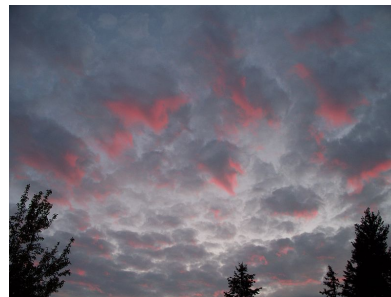
Clouds

- A **cloud** is a visible mass of droplets or frozen crystals floating in the atmosphere above the surface of the Earth.
- Clouds are divided into two general categories: layered and convective. These are named **stratus clouds** (or stratiform, the Latin *stratus* means "layer") and **cumulus clouds** (or cumuliform; *cumulus* means "piled up"), respectively.
- These two cloud types are divided into four more groups that distinguish the cloud's altitude. Clouds are classified by the cloud base height, not the cloud top.



Cloud Albedo

- **Cloud albedo** varies from less than 10% to more than 90%.
- Extent depends on drop sizes, liquid water or ice content, thickness of the cloud, and the sun's zenith angle.
- Low, thick clouds such as **Stratocumulus** primarily reflect incoming solar radiation, whereas high, thin clouds such as **Cirrus** tend to transmit it to the surface but then trap outgoing infrared radiation, contributing to the greenhouse effect.



Global Dimming

- The recently recognized phenomenon of **global dimming** is thought to be caused by changes to the reflectivity of clouds due to the increased presence of aerosols and other particulates in the atmosphere.
- Effects photosynthetic rates and disrupts productivity in ecosystems around the globe.

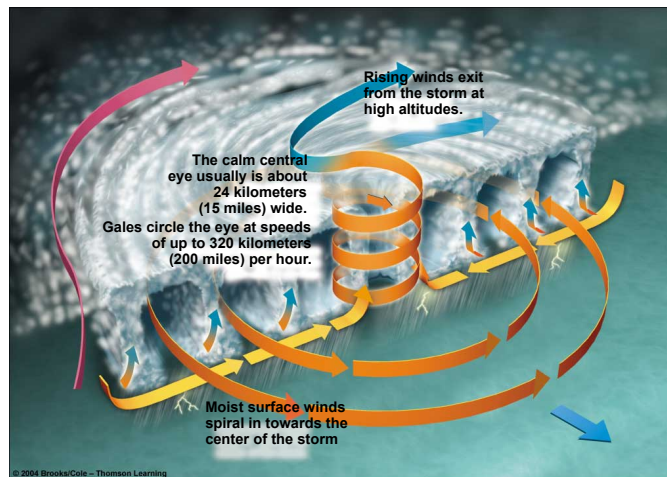


Hurricanes

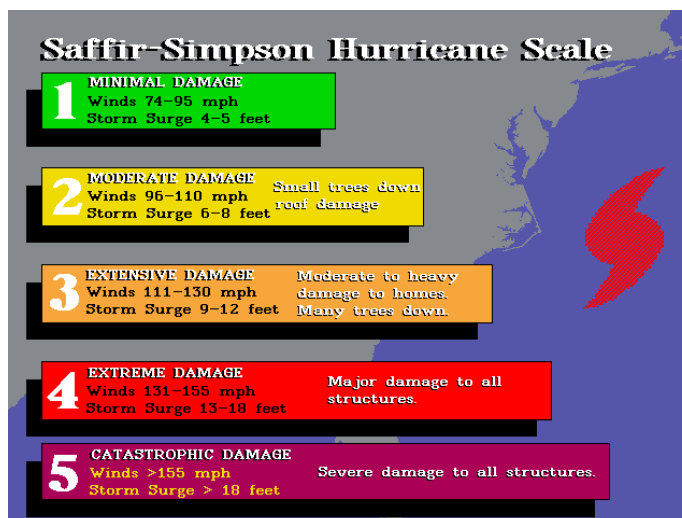
- A **tropical cyclone** is a storm system characterized by a **low pressure** center and numerous thunderstorms that produce strong winds and flooding, rain.
- Tropical cyclones feed on heat released when moist air rises, resulting in condensation of water vapor contained in the moist air.



Diagram of a Hurricane

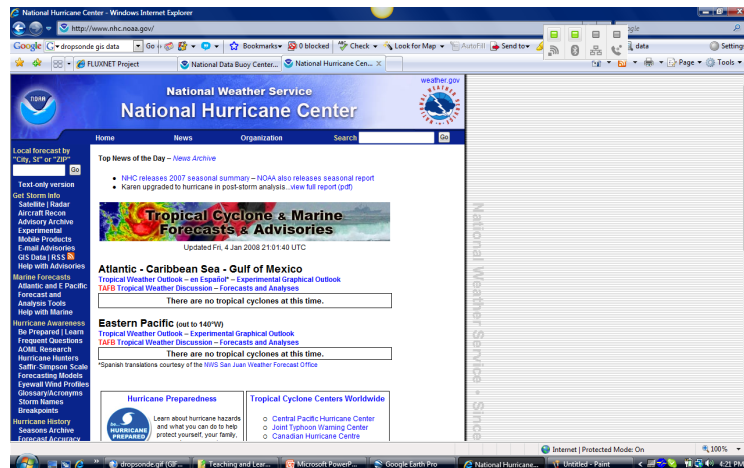


Saffir-Simpson Scale



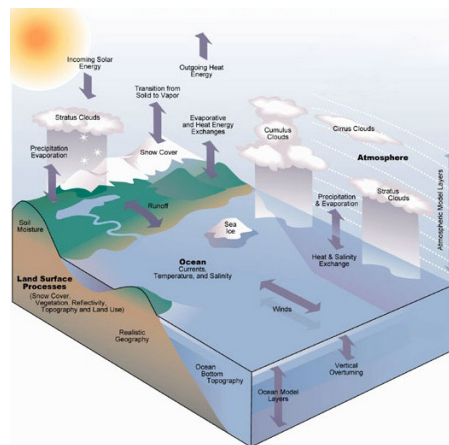
National Hurricane Center

<http://www.nhc.noaa.gov/>



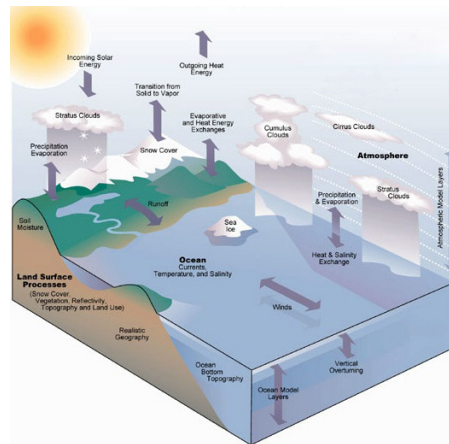
Everything is Connected

- The ocean, atmosphere, and land interact in complex ways, producing a climate in which life thrives.
- Even seemingly small changes in one area can have a ripple effect, sparking changes in other areas. For example, changes in the distribution of warm water in the ocean, such as occurs in the tropical Pacific during an El Niño event, alter evaporation and cloud formation patterns. These changes in turn affect rainfall and wind patterns.



Everything is Connected, cont'd

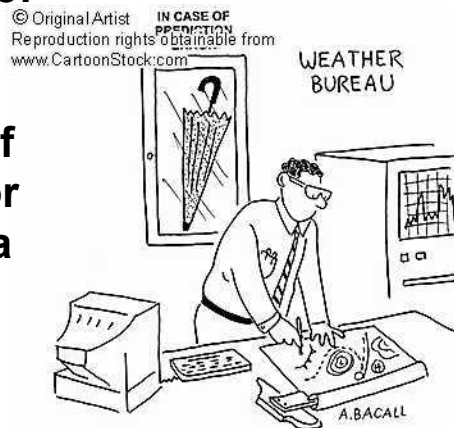
- **Changes in wind patterns may affect ocean surface currents and upwelling, which may impact the availability of nutrients on which marine ecosystems depend.**
- **Understanding these connections is essential as we grapple with the implications of climate change and our actions that may contribute to it.**



Weather forecasting

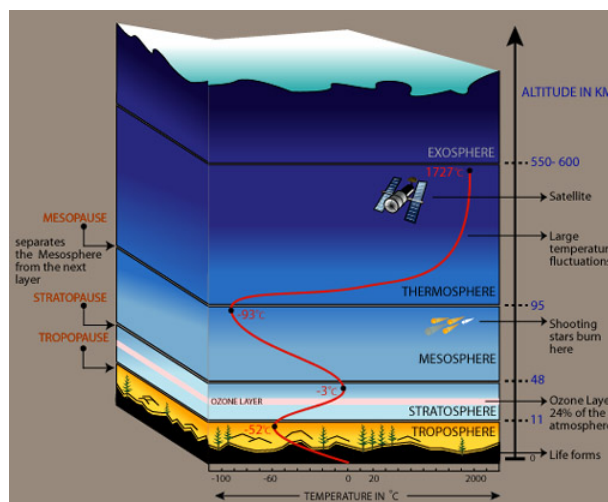
Weather Forecasting

- **Weather forecasting is the application of science and technology to predict the state of the atmosphere for a future time and a given location.**



Layers of the Atmosphere

The atmosphere is a chaotic system, so small changes to one part of the system can grow to have large effects on the system as a whole.



Weather Variables

- Temperature
- Pressure
- Moisture Content
- Precipitation
- Light
- Cloud Cover
- Wind Direction & Speed

OVERVIEW OF SOME TOOLS IN METEOROLOGY

- Barometers (pressure)
- Psychrometers (Moisture)
- Doppler Radar (wind motion)
- Marine Bouys (ocean temp and movement)
- Radiosondes and Rawinsondes
- GPS Dropsondes
- Satellite Images
- Numerical modeling (computer forecasting)

Barometers

- A **barometer** is an instrument used to measure atmospheric pressure.
- It can measure the pressure exerted by the atmosphere by using water, air, or mercury.
- Pressure tendency can forecast short term changes in the weather.



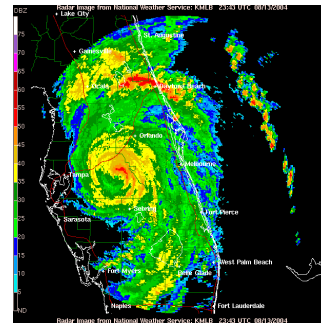
Psychrometers

- A wet-bulb thermometer is an instrument which may be used to infer the amount of moisture in the air.

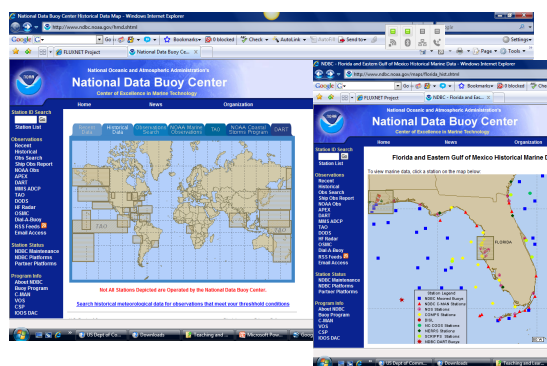


Doppler Radar

- A **doppler radar** is a radar using the doppler effect of the returned echoes from targets to measure their radial velocity.
- The microwave signal sent by the radar antenna's directional beam is reflected toward the radar and compared in frequency, up or down from the original signal



Marine Bouys

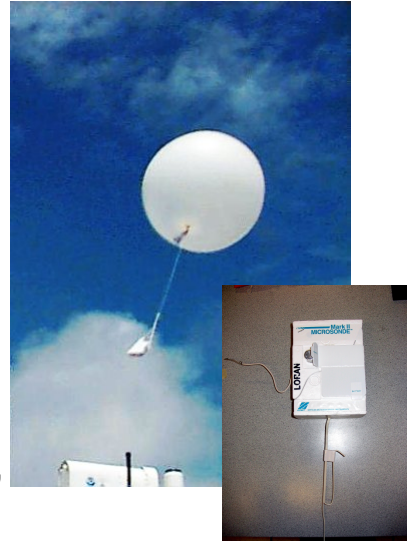


Ocean and weather data are gathered by sensors on the bouys and then transmitted to the National Data Buoy Center
<http://www.ndbc.noaa.gov/hmd.shtml>

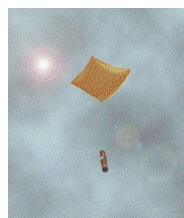
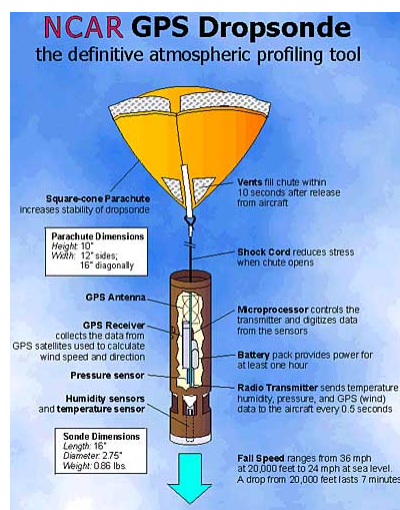


Radiosondes and Rawinsondes

- A **radiosonde** is a unit for use in weather balloons that measures various upper atmospheric parameters and transmits them to a fixed receiver (*Sonde* is French for *probe*).
- A **rawinsonde** is a radiosonde that is designed to also measure wind speed and direction.
- Data recorded: latitude, longitude, altitude, temperature, barometric pressure, humidity



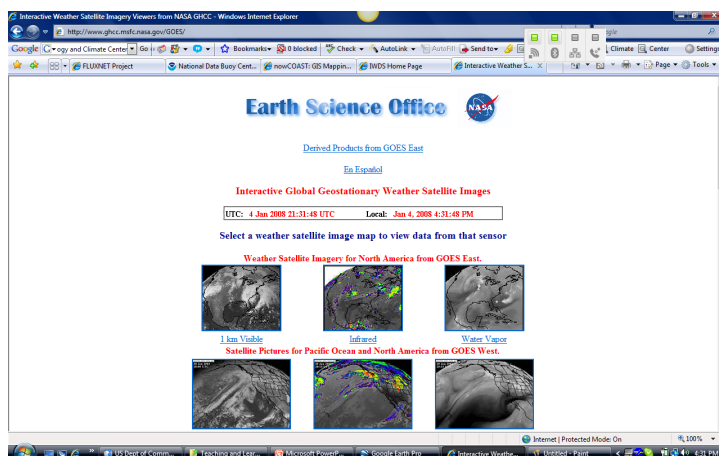
GPS Dropsonde



Data Recorded:
temperature,
humidity, pressure
and GPS wind data.

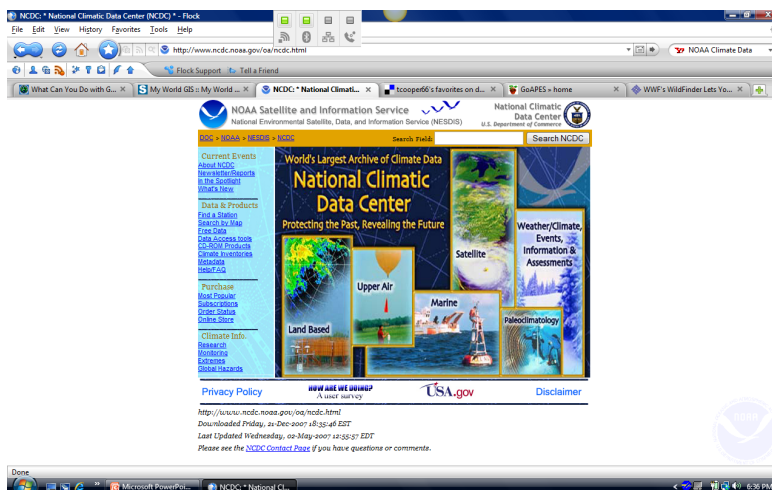
GOES Weather Satellite Images

<http://www.ghcc.msfc.nasa.gov/GOES/>



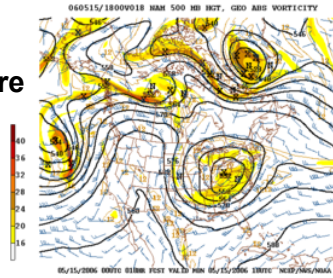
National Climate Data Center

<http://www.ncdc.noaa.gov/oa/ncdc.html>



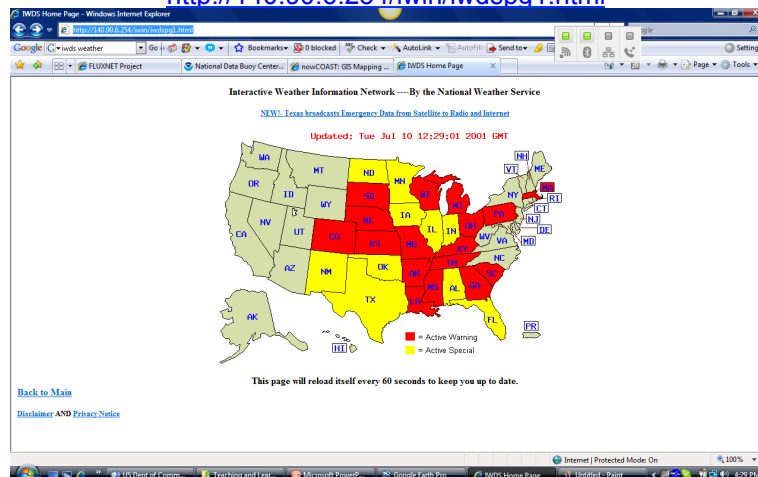
Forecasting Models

- A model, in this context, is a computer program that produces meteorological information for future times at given positions and altitudes.
- These equations are nonlinear and are impossible to solve exactly.
- Global models often use **spectral methods** for the horizontal dimensions and **finite difference methods** for the vertical dimension, while regional models usually use **finite-difference methods** in all three dimensions.



Interactive Weather Information (IWDS)

<http://140.90.6.254/iwin/iwdspg1.html>



Earth's Extremes

- The **coldest** air temperature ever recorded on Earth is -89.2°C (-129°F), at Vostok Station, Antarctica on 21 July 1983.
- The **hottest** air temperature ever recorded was 57.7°C (135.9°F) at Al 'Aziziyah, Libya, on 13 September 1922.
- The highest recorded average annual temperature was 34.4°C (93.9°F) at Dallol, Ethiopia.
- The **coldest** recorded average annual temperature was -55.1°C (-67°F) at Vostok Station, Antarctica.
- The **coldest** average annual temperature in a permanently inhabited location is at Eureka, Nunavut, in Canada, where the annual average temperature is -19.7°C (-3°F)

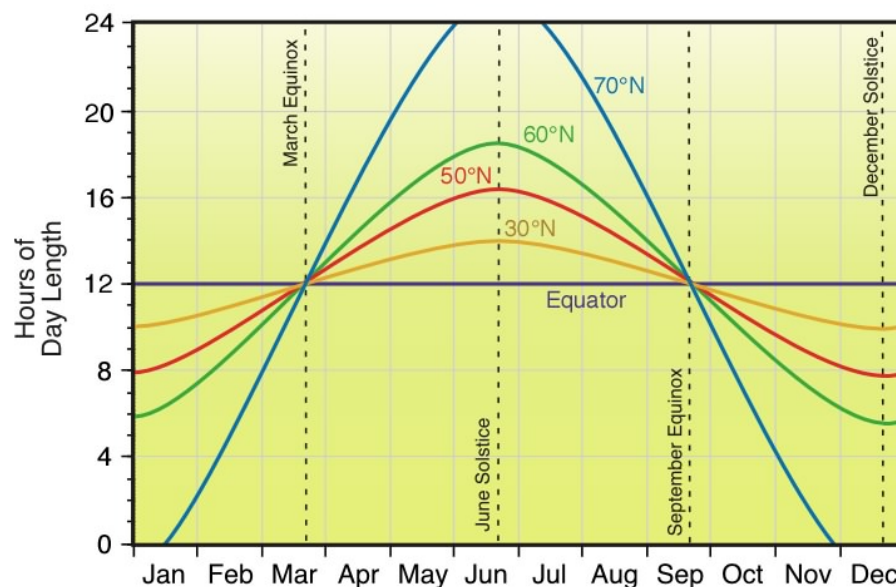


Figure 6i-2: Annual variations in day length for locations at the equator, 30, 50, 60, and 70° North latitude.

Making Meaning: What does the graph above tell you?

-
-
-
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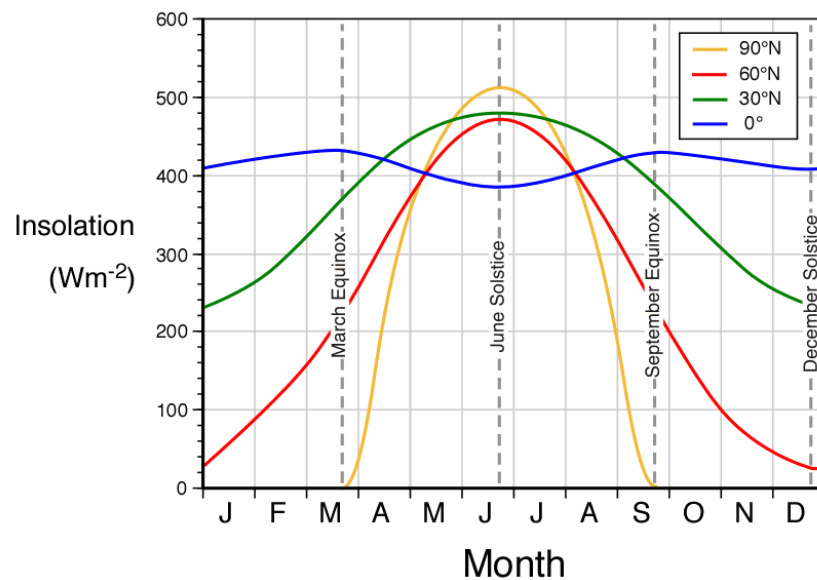


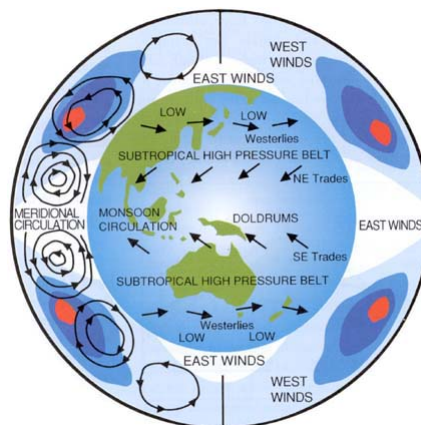
Figure 6i-3: Monthly values of available insolation in Wm^{-2} for the equator, 30, 60, and 90° North.

Making Meaning: What does the graph above tell you?

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Coriolis Effect: Do toilets flush backwards in Australia?

- Earth's rotation then causes curvature of the flow of wind via the Coriolis effect.
- Movements of air in the atmosphere and water in the ocean are notable examples of this behavior, rather than flowing directly from areas of high pressure to low pressure, as they would on a non-rotating planet, winds and currents tend to flow to:
 - The RIGHT of this direction in the N Hem
 - The LEFT of this direction S Hem
- This effect is responsible for the rotation of large cyclones and tornadoes



What is Climate?

Climate

- **Encompasses the temperatures, humidity, rainfall, atmospheric particle count and numerous other meteorological factors in a given region over long periods of time, as opposed to the term weather, which refers to current activity.**

Climate and Its Variables

- Time
- Precipitation
- Temperature
- Greenhouse Gasses
- Topography
- Volcanic Activity
- Human Geography